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Influence of oil transformer cooling on its lifetime

Abstract: This paper deals with the influence of thermal stress on the transformer lifetime. Transformer lifetime is influenced largely by overheating of windings and then the insulation ages and reduces its electrical insulating properties. Proper placement of electrical transformer parts can help to ensure the more uniform distribution of temperature field and to increase the transformer lifetime.

Keywords: temperature field; ANSYS; transformer insulation aging

I. INTRODUCTION

Every electrical device operates with a certain efficiency, which indicates what portion of an electrical energy is transformed into the desired form of energy. The remaining part of the electrical energy is converted to losses. Losses may be generated for example in the windings, in structural core or as the mechanical losses and so on. These losses are then converted to heat and warm up those parts in which such losses are incurred and subsequently they warm up the surrounding parts and devices by heat transferring. The amount of warming is related to the lifetime of the device, so it is necessary to take away the heat to the surrounding.

II. CALCULATION OF WARMING OF OIL TRANSFORMER 22/0,4 KV

As an example of calculation algorithm there was chosen the distribution oil transformer that insulation was made from thermal insulation of Class A. Windings were made of aluminum. Other parameters for the calculation were as follows:

- apparent power S_n = 630 kVA,
- frequency f = 50 Hz,
- line voltage U = 22000/440 V,
- rated current of primary winding I_{1n} = 16,53 A,
- rated current of secondary winding I_{2n} = 909,33 A,
- resistance of one phase of primary winding R_1 = 7,5282875674 Ω (on U_1 base),
- resistance of one phase of secondary winding R_2 = 0,00100881 Ω (on U_2 base),
- magnetic flux density in core of the transformer B = 1,45 T,
- core weight m = 604,545 kg.

A. Calculation of transformer losses

Winding losses of higher voltage in one phase are:

$$\Delta P_1 = R_1 \cdot I_{1n}^2 = 7{,}5282875674 \cdot 16{,}53^2 = 2057{,}03\ \mathrm{W} \tag{1}$$

Winding losses of lower voltage in one phase are:

$$\Delta P_2 = R_2 \cdot I_{2n}^2 = 0{,}00100881 \cdot 909{,}33^2 = 834{,}17\ \mathrm{W} \tag{2}$$

Specific losses in the metal-based oriented sheets for the magnetic induction B = 1,45 T are Δp = 1,1 W·kg^{-1} and recalculated to core mass:

$$\Delta P_{Fe} = \Delta p \cdot m_{Fe} = 1{,}1 \cdot 604{,}545 = 665\ \mathrm{W} \tag{3}$$

B. Total losses in the transformer

Total losses in the transformer can be calculated as follows:

$$\Delta P_c = 3 \cdot \Delta P_1 + 3 \cdot \Delta P_2 + \Delta P_{Fe} = 3 \cdot 2057{,}03 + 3 \cdot 834{,}17 + 665 = 9338{,}6\ \mathrm{W} \tag{4}$$

C. Transformer tank

The transformer of dimensions 1015 × 375 × 995 mm (length × width × height) was placed in a tank of given dimensions 1100 × 450 × 1200 mm. Consequently, tank surface was enlarged by adding of cooling waves from circumferential metal plate.

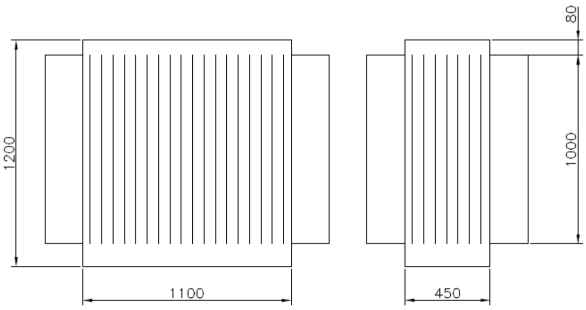


Figure 1. Basic dimensions of transformer tank

D. Calculation of tank warming

Oil in the tank, in which the transformer is placed, takes away the heat from the winding surface to reduce the winding temperature by 10 to 15 °C. Therefore, it is necessary to perform such a tank concept that the medium warming was up to 47 °C. For the presented transformer there was implemented calculation and thermal simulation in ANSYS for waves of 200 mm and 300 mm in length. In both cases, the height of the tank waves was 1000 mm.

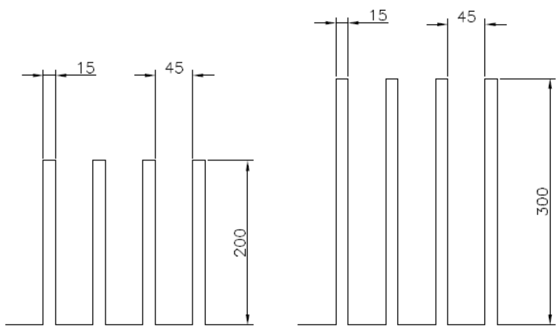


Figure 2. Concept of waves on a tank

E. Tank warming of 200 mm long waves

Required parameters for calculation:

- coefficient of imperfect convection $\gamma = 0{,}9$,
- convection heat transfer coefficient $\alpha_k = 6{,}4\ \mathrm{W{\cdot}K^{-1}{\cdot}m^{-2}}$,
- radiation heat transfer coefficient $\alpha_{pr} = 6{,}7\ \mathrm{W{\cdot}K^{-1}{\cdot}m^{-2}}$,
- convection surface $S_k = 23\ \mathrm{m^2}$,
- radiation surface $S_{pr} = 4{,}7\ \mathrm{m^2}$.

Then, the tank warming can be calculated as follows:

$$\Delta\vartheta_n = \frac{\Delta P_c}{S_k \cdot \left(\alpha_k \cdot \gamma + \alpha_{pr} \cdot \dfrac{S_{pr}}{S_k}\right)} = \frac{9338{,}6}{23 \cdot \left(6{,}4 \cdot 0{,}9 + 6{,}7 \cdot \dfrac{4{,}7}{23}\right)} = 56{,}95\ ^\circ\mathrm{C} \quad (5)$$

F. Tank warming of 300 mm long waves

The coefficients of imperfect convection and heat transfer by convection and radiation are the same as in the previous case. In this case there were only enlarged cooling surfaces as follows:

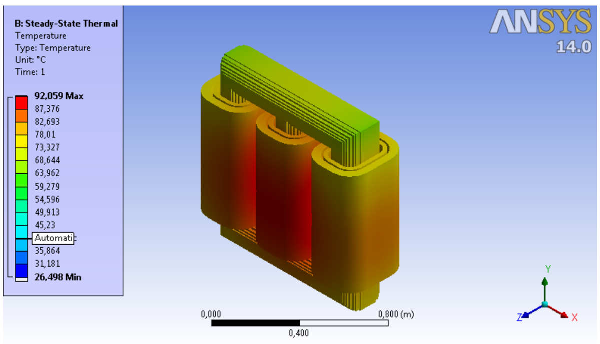
- convection surface $S_k = 33{,}1\ \mathrm{m^2}$,
- radiation surface $S_{pr} = 5{,}5\ \mathrm{m^2}$.

Tank warming can be calculated as follows:

$$\Delta\vartheta_n = \frac{\Delta P_c}{S_k \cdot \left(\alpha_k \cdot \gamma + \alpha_{pr} \cdot \dfrac{S_{pr}}{S_k}\right)} = \frac{9338{,}6}{33{,}1 \cdot \left(6{,}4 \cdot 0{,}9 + 6{,}7 \cdot \dfrac{5{,}5}{33{,}1}\right)} = 41{,}04\ ^\circ\mathrm{C} \quad (6)$$

III. SOLUTION OF TEMPERATURE FIELD OF OIL TRANSFORMER IN ANSYS

Simulation of temperature field distribution was performed in ANSYS. The ambient temperature was chosen 20 °C, which is the maximum permissible average annual temperature, and thus it is also the average load of the transformer during the year.



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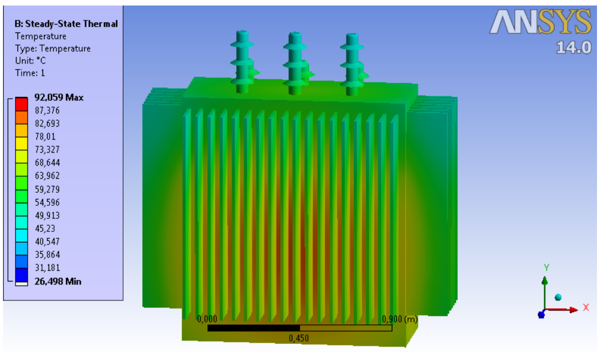

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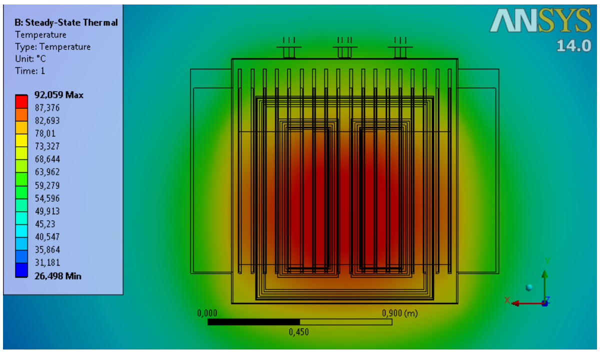
Figure 3. a) The temperature of particular transformer parts (waves: 200 mm); b) Distribution of temperature field on the transformer tank (waves: 200 mm)



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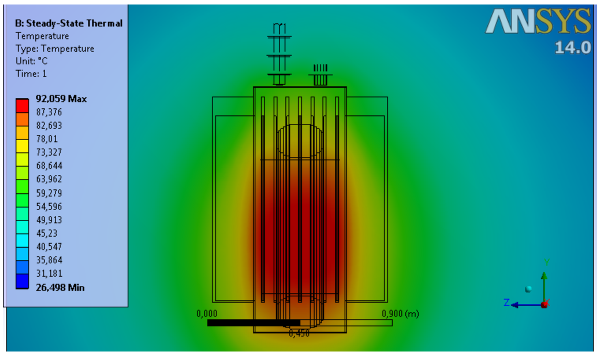

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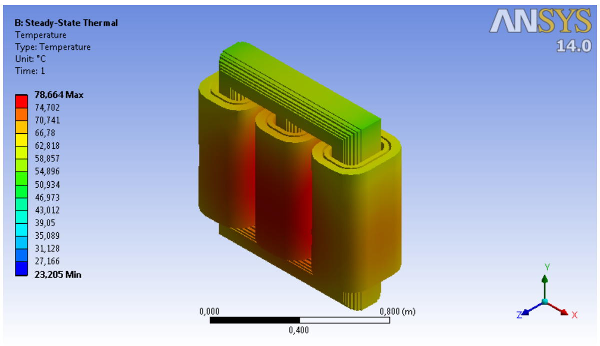
Figure 4. a) Distribution of temperature field in the transformer environment seen from the front (waves: 200 mm); b) Distribution of temperature field in the environment seen from the side (waves: 200 mm)



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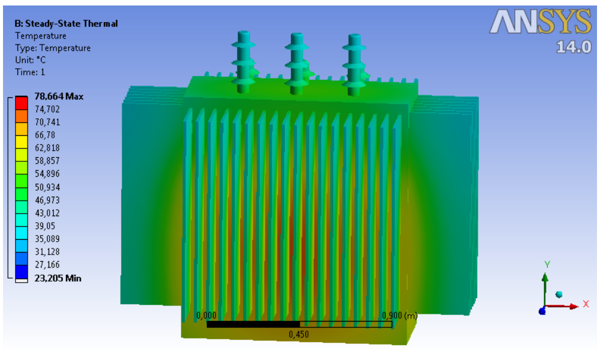

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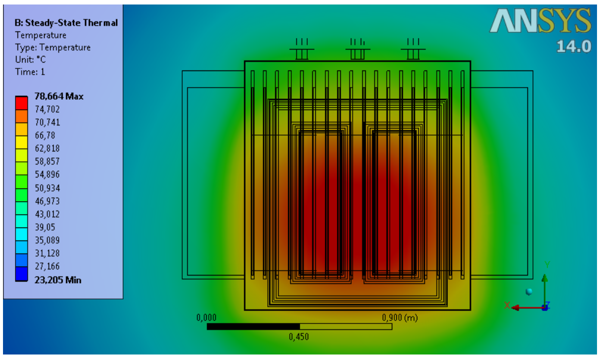
Figure 5. a) The temperature of particular transformer parts (waves: 300 mm); b) Distribution of temperature field on the transformer tank (waves: 300 mm)



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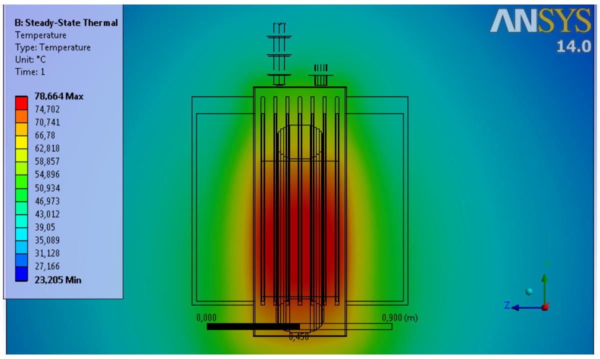

b)

Figure 6. a) Distribution of temperature field in the transformer environment seen from the front (waves: 300 mm); b) Distribution of temperature field in the environment seen from the side (waves: 300 mm)

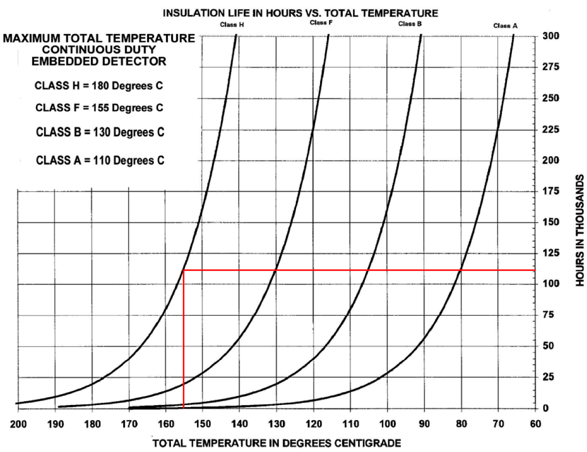

Figure 7 Insulation lifetime in dependence on the temperature size [7]

The suggested cooling concept was implemented for oil distribution transformer of power output $S_n = 630$ kVA. The transformer was placed in a tank of given dimensions 1100 × 450 × 1200 mm (length × width × height). Cooling was performed for 200 and 300 mm long waves. Estimated warming was 56,95 °C for the tank of 200 mm long waves. One can see from the simulation in Fig. 3 and Fig. 4 that the temperature of most stressed parts was 92,059 °C. This concept is unacceptable, because there is the transcended allowable warming of transformer oil and windings. At higher ambient temperatures it threats to a decomposition of oil and then to formation of hydrogen gas. This solution offers a lifetime of 5,5 years (according to Fig. 7). By extending the length of the waves to 300 mm the medium warming of a tank was 41,04 °C. The temperature of the most stressed parts was 78,664 °C in a steady state in ANSYS simulation by ambient temperature of 20 °C (Fig. 5 and Fig. 6). The transformer lifetime is about 17 years in this case (Fig. 7). Tank concept with 300 mm long waves is more expensive, because it takes more external material to create waves on the tank, but it will extend the lifetime for more than 12 years.

Warming calculations and thermal simulations in steady state were realized at 100 % transformer operation load. On the other hand, in common operation the most transformers are rarely operated at full rated power. Warming of these devices will be smaller and also there will be extended their lifetime.

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